HOW MUCH PLUTONIUM DOES NORTH KOREA REALLY HAVE?

Jared S. Dreicer

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Abstract
In a previous study,¹ as part of the Global Nuclear Material Control Model effort, we estimated the maximum quantity of plutonium that could be produced in thermal research reactors in the potential nuclear weapon states (including North Korea), based on their declared power level. D. Albright has estimated the amount of plutonium the North Koreans may have produced since 1986 in the 5-megawatt-electric “power” reactor at Yongbyon. Albright provided an upper-bound estimate of 53 kilograms of weapon-grade plutonium produced cumulatively if the gas-graphite (magnox) reactor had achieved a load factor of 0.80. This cumulative estimate of 53 kilograms ignores the potential plutonium production in the 8-megawatt-thermal research reactor, IRT-DPRK. To better quantify the cumulative North Korean production, we conducted a study to estimate the amount of plutonium that could have been produced in the IRT-DPRK research reactor operating at the declared power level during the entire period it has operated, including a period it was not safeguarded.

Introduction
David Albright published his estimate and assumptions in the October 1994 Bulletin article “How Much Plutonium Does North Korea Have?”² Albright estimated the plutonium content of the removed 1989 irradiated fuel from the “power” reactor at 7 to 14 kilograms, resulting in, at most, 6 to 13 kilograms of separated plutonium.³ While Albright’s estimates are reasonable, he only addressed the question of how much plutonium could have been produced in the 5-megawatt-electric (MWₑ) power reactor since 1986.⁴ In order to determine how much plutonium the North Koreans (Democratic People’s Republic of Korea, DPRK) may have, it is also necessary to estimate the quantity of plutonium produced in the 8-megawatt-thermal (MWₜ) IRT research reactor. We estimate that, at most, an additional 6 to 33 kilograms of plutonium could have been produced cumulatively in the research reactor operating at the declared power level during the entire period it has operated, including a 12-year period it was not safeguarded, resulting in a total of 13 to 47 kilograms of plutonium possibly produced in both the research and power reactors.

Background
In the 1960s, the Soviet Union (USSR) provided the DPRK an IRT research reactor (IRT-DPRK). The pool-type IRT-DPRK, with an initial power of 2 MWₑ, was not placed under safeguards until 1977; it first went critical in August 1965. The DPRK signed the Nuclear Non-Proliferation Treaty in 1985, but did not ratify a comprehensive safeguards agreement associated with the regime until April 9, 1992. In May 1992, the DPRK provided the International Atomic Energy Agency (IAEA) with their initial nuclear material and facility declaration. As a result of the IAEA’s verification process, discrepancies were discovered in the DPRK’s initial declaration of plutonium production. Subsequently, the DPRK admitted that the IRT-DPRK research reactor was the source of plutonium separated in 1975. Despite this history, published estimates of DPRK plutonium production have only accounted for the 5-MWₑ “power” reactor production and have not taken into account the IRT-DPRK. In this study we have estimated the potential plutonium production in the IRT-DPRK research reactor during the entire period it has operated at various declared power levels.
In addition to the research reactor, the DPRK received laboratory-scale processing equipment (“hot cells”) from the Soviet Union in the 1960s. The IRT-DPRK is located in Yongbyon and the laboratory-scale hot cells are located in Pyongyang. Additionally, a small-lab “0.1-MW nuclear research lab called a critical facility,” which included hot cells, was constructed at Yongbyon. The IRT-DPRK was placed under IAEA safeguards when a Type 66 trilateral (USSR, DPRK, and IAEA) safeguards agreement, which is facility, material, or equipment specific, was initiated on July 20, 1977, essentially 12 years after it first went critical.

As part of the initial 1992 safeguards declaration and to resolve the discrepancies raised by it, the DPRK admitted utilizing the hot cells at Pyongyang and Yongbyon for plutonium separation as early as 1975, prior to the 1977 Type 66 safeguards. The Chinese and Soviets at the Dubna nuclear research facilities trained DPRK scientists starting in the 1960s. During this training the DPRK technicians probably obtained knowledge and technology concerning plutonium reprocessing. Having separated plutonium at least four different times, the DPRK admitted separating plutonium in 1975 and 1990, and the IAEA discovered americium-241 indicating that plutonium was also separated in 1989 and 1991. It is obvious that the DPRK had extensive understanding of this process and technology by the 1990s.

As early as 1965, the DPRK had an indigenous nuclear infrastructure, including technically capable scientists and technicians, the IRT-DPRK research reactor, critical and subcritical facilities, and a quality source of natural uranium at Pyongsan. The DPRK’s interest in plutonium is indicated to be the early 1970s since plutonium separation was achieved in 1975.

Since the IRT-DPRK was the source of plutonium for the 1975 separation, the question becomes, What quantity of plutonium could have been produced in the IRT-DPRK during the entire period it has operated?

**Plutonium Production In The IRT-DPRK Research Reactor**

The plutonium production rate in a reactor corresponds to the power level that is proportional to the flux. Since the plutonium production rate corresponds to the power level, it is possible to estimate the quantity of plutonium produced based solely on the power level. The actual rate of plutonium production in a reactor is dependent on a number of specific production factors including fuel enrichment, target configurations, and reactor operation. Basing a plutonium production estimate on power level requires knowledge of the operating thermal power level for the reactor. The IAEA maintains a Directory of Nuclear Research Reactors, where the declared maximum operating power level for research reactors are reported.

These calculations represent an upper-bound estimate of the maximum plutonium production (EMPu) potential; more accurate neutronic calculations require specific production factor knowledge. Assuming that the DPRK operated the research reactor at a 0.90 load factor and that the potential plutonium production rate is 0.65–0.70 g Pu/MWt-d results in an upper bound estimate expression for the maximum possible quantity of plutonium that could be produced in an one-year period using fertile targets (238U or natural uranium).

The IRT-DPRK was recently declared as having an 8-MWt power level; however, it was initially constructed for 2 MW, and was subsequently upgraded to 4-MWt power level. For simplicity, our estimates assume that the reactor was operated for roughly the same duration at each of the three different declared power levels; the dates of declared modification are in conflict.
Table 1 summarizes the estimated maximum plutonium production ($\text{EMP}_{\text{dec}}$) in the IRT-DPRK for one year, based on the declared reactor power level and the time required to produce a significant quantity (SQ), 8 kilograms, of fissile plutonium as defined by the IAEA. For example, at a declared power level of 8 MW, the $\text{EMP}_{\text{dec}}$ is 1.792 kilograms/year, and it would take 4.46 years to produce an SQ.

### Table 1. Estimated Plutonium Production For The Declared Power Level ($\text{EMP}_{\text{dec}}$)

<table>
<thead>
<tr>
<th>Declared Power Level (MW)</th>
<th>$\text{EMP}_{\text{dec}}$ (kg/yr)</th>
<th>Years to Produce 1 SQ (8 kg) (yr/SQ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.448</td>
<td>17.86</td>
</tr>
<tr>
<td>4</td>
<td>0.896</td>
<td>8.93</td>
</tr>
<tr>
<td>8</td>
<td>1.792</td>
<td>4.46</td>
</tr>
</tbody>
</table>

The cumulative maximum plutonium production (CMPu) reflects the total quantity of plutonium that could have been produced, based on the number of years that the IRT-DPRK operated at the three declared power levels. There are two possible combinations for operation of the IRT-DPRK at the declared operating power level, either under the presence of safeguards or without safeguards. Because of the IRT-DPRK’s low-power rating relative to IAEA safeguards criteria, which do not require an analysis for reactors with a thermal power of 25 MW, or less, it is unclear whether or not the safeguards were adequate after it was placed under safeguards in 1977.

**Declared Operating Power Level—No Safeguards**

In the first four columns of Table 2 is the declared operating power, the EMPu, the number of years that would be required to produce an SQ of plutonium, and the number of years of operation. The fifth column (CMPu [kg/years-operating] values) in Table 2 assumes no safeguards were implemented during the entire period of operation for the IRT-DPRK. These CMPu values assume *unrestricted* plutonium production opportunity.

**Declared Operating Power Level and Duration Of Safeguards**

The last two columns of Table 2 summarize the number of years the IRT-DPRK actually operated at the particular power level without safeguards implemented and the resulting CMPu (without safeguards for 12 years and with safeguards for 19 years). These two columns utilize the declared operating power and assume safeguards were applied on August 1977. The CMPu values assume *restricted* plutonium production opportunity after safeguards were applied. At most the IRT-DPRK could have produced 6 kilograms of plutonium during those twelve years, assuming that it operated at 2 MW for ten years and at 4 MW for two years.

### Table 2. Cumulative Maximum Plutonium Production ($\text{CMP}_{\text{dec}}$) for Declared Power Level with No Safeguards During Period of Operation and Accounting for Duration of Safeguards Implementation for IRT-DPRK.

<table>
<thead>
<tr>
<th>Declared Power Level (MW)</th>
<th>EMPu (kg/yr)</th>
<th>Years to SQ (8 kg)</th>
<th># Years Operate to 8/96</th>
<th>CMPu, No Safeguards (kg/yr-oper)</th>
<th># Years Operate, No Safeguards</th>
<th>CMPu with Safeguards (kg/yr-oper)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.448</td>
<td>17.86</td>
<td>10.00</td>
<td>4.48</td>
<td>10.00</td>
<td>4.48</td>
</tr>
<tr>
<td>4</td>
<td>0.896</td>
<td>8.93</td>
<td>10.00</td>
<td>8.96</td>
<td>2.00</td>
<td>1.79</td>
</tr>
<tr>
<td>8</td>
<td>1.792</td>
<td>4.46</td>
<td>11.00</td>
<td>19.71</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>33.15</td>
<td></td>
<td>6.27</td>
</tr>
</tbody>
</table>
Feasible Plutonium Production Estimations

Heat dissipation is the dominant reactor design consideration, thus the primary thermal criterion of this type of reactor is the requirement to prevent nucleate boiling in any of the fuel. Prevention of nucleate boiling requires that the fuel surface temperature not surpass the saturation temperature by more than 10°C on average. The power level at which this type of reactor can operate due to the correlated heat load is limited by this thermal principle. Sufficient heat dissipation keeps the fuel’s surface temperature slightly above the saturation temperature at the maximum flux produced by the power level. These reactors have been designed and engineered to exceed this thermal criteria for safety. This results in a fundamental problem from the nonproliferation perspective: that the specified threshold only refers to the declared operating power of the reactor, not the feasible maximum power level. With minor or no engineering modifications, it is possible to operate a reactor at up to 50% greater power, since as a rule the reactors have been conservatively designed from a thermal perspective. To increase the power level, a number of variables can be exploited: increasing the heat transfer area of the target material, the velocity of coolant flow, and the capacity of the secondary cooling system, decreasing the temperature of the primary coolant prior to inlet, arranging the target configuration, and raising the reactor pressure, which increases the saturation temperature (for tank-type reactors that have a closed primary-coolant system). Thus, the declared maximum operating power level is often significantly lower than the required heat dissipation rate. The IAEA reported level only refers to the declared operating power of the reactor, not the feasible maximum power level.

We estimated the plutonium production using the feasible (50% greater than declared) power levels. The corresponding feasible reactor power levels are 3, 6, and 12 MW. Table 3 summarizes the feasible EMPu (EMPuFeas) in the IRT-DPRK for one year, based on the feasible reactor power level and the time required to produce an SQ. For example, at a feasible power level of 12 MW (50% greater than the declared 8 MW), the EMPuFeas is 2.688 kilograms/year and it would take 2.97 years to produce an SQ.

Table 3. Estimated Plutonium Production Using the Feasible Power Level (EMPuFeas) for the IRT-DPRK. Feasible Power is 50% Greater than Declared.

<table>
<thead>
<tr>
<th>Feasible Power Level (MW)</th>
<th>EMPuFeas (kg/yr)</th>
<th>Years to Produce 1 SQ (8 kg) (yr/SQ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.672</td>
<td>11.90</td>
</tr>
<tr>
<td>6</td>
<td>1.344</td>
<td>5.95</td>
</tr>
<tr>
<td>12</td>
<td>2.688</td>
<td>2.97</td>
</tr>
</tbody>
</table>

Feasible Operating Power Level—No Safeguards

The first five columns of Table 4 present the feasible operating power, the EMPu, the number of years required to produce an SQ of plutonium, and the number of years of operation. The fifth column (CMPu values assume no safeguards) in Table 4 were implemented during the entire period of operation for the IRT-DPRK. These CMPu values assume the unrestricted plutonium production opportunity. This could have resulted in the DPRK having produced more than an SQ. 49.73 kilograms of plutonium could have been produced cumulatively if the IRT-DPRK operated at 3 and 6 MW for 10 years each and then at 12 MW for the remaining 11 years during operation without safeguards.
Table 4. Cumulative Maximum Plutonium Production (CMPu<sub>feas</sub>) for Feasible Power Level with No Safeguards During Entire Period of Operation and Accounting for Duration of Safeguards Implementation for IRT-DPRK.

<table>
<thead>
<tr>
<th>Feasible Power Level (MW)</th>
<th>EMPu (kg/yr)</th>
<th>Years to SQ (8 kg)</th>
<th># Years Operate to 8/96</th>
<th>CMPu, No Safeguards (kg/yr-oper)</th>
<th># Years Operate, No Safeguards</th>
<th>CMPu with Safeguards (kg/yr-oper)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.672</td>
<td>11.90</td>
<td>10.00</td>
<td>6.72</td>
<td>10.00</td>
<td>6.72</td>
</tr>
<tr>
<td>6</td>
<td>1.344</td>
<td>5.95</td>
<td>10.00</td>
<td>13.44</td>
<td>2.00</td>
<td>2.69</td>
</tr>
<tr>
<td>12</td>
<td>2.688</td>
<td>2.97</td>
<td>11.00</td>
<td>29.57</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>49.73</td>
<td></td>
<td>9.41</td>
</tr>
</tbody>
</table>

**Feasible Operating Power Level and Duration Of Safeguards**

The last two columns of Table 4 summarize the number of years the IRT-DPRK could have operated at the feasible power level without safeguards implemented and the resulting CMPu (without safeguards for 12 years and with safeguards for 19 years). These two columns utilize the feasible operating power and assume safeguards were applied on August 1977. The CMPu values assume restricted plutonium production opportunity after safeguards were applied. At most, the IRT-DPRK could have produced 9 kilograms of plutonium during those twelve years, assuming that it operated at 3 MW<sub>e</sub> for ten years and at 6 MW<sub>e</sub> for two years.

**Potential Plutonium Production In The IRT-DPRK**

The power level modifications from 2 to 4 and then 8 MW<sub>e</sub> of the IRT-DPRK have an impact on the maximum possible plutonium production; we have estimated the quantity that could be produced depending on the period of operation at a specific declared power level, at various load factors. Figure 1 illustrates the potential CMPu for both the declared and feasible reactor power levels. Figure 1A (1B) presents the cumulative quantity of plutonium that could be produced assuming the IRT-DPRK operated at the declared (feasible) power levels of 2 (3) and 4 (6) MW<sub>e</sub> for 10 years each, then 8 (12) MW<sub>e</sub> for the remaining 11 years, using load factors from 0.5 to 0.9. Figure 1C (1D) presents the cumulative plutonium produced for the entire operating period of 31 years at each load factor for the declared (feasible) power level. As shown in Figure 1C, the cumulative plutonium produced for the declared power levels at load factor 0.9 is about 33 kilograms of plutonium. The 33 kilograms cumulative assumes that the IRT-DPRK operated only at the declared power levels and that the safeguards did not restrict the opportunity for plutonium production. The absolute upper bound estimate for the production of plutonium, depicted in Figure 1D, assumes that the IRT-DPRK operated at the feasible 3 and 6 MW<sub>e</sub> power levels for 10 years each and a 12 MW<sub>e</sub> power level for the remaining 11 years at a load factor of 0.9, resulting in roughly 50 kilograms plutonium, cumulatively.

**Conclusions**

The DPRK may not have had the technical capability and desire to utilize the IRT-DPRK for plutonium production as early as 1965; indeed, the reactor may never have been for such a purpose. However, the DPRK separated plutonium in 1975, had a source of fertile material, and had other required technical infrastructure. It is thus necessary to determine what could have been produced in the IRT-DPRK research reactor in addition to what could have been, or was, produced in the 5 MW<sub>e</sub> “power” reactor.
From a theoretic proliferation perspective, the IRT-DPRK could have produced an upper bound of about 50 kilograms plutonium cumulatively if the feasible power level had been achieved at a load factor of 0.90. This is very unlikely since it would have required consistent operation of the IRT-DPRK at a level of virtually unachievable efficiency for 31 years. It is also theoretically possible, yet unlikely, that the DPRK produced about 33 kilograms of plutonium cumulatively based on the assumed periods of operation at the declared power levels; this also would have required a highly efficient operation of the IRT-DPRK. A more pragmatic perspective is that between 6 to 33 kilograms of plutonium at most could have been produced in the IRT-DPRK reactor operating at the declared power level during the entire period it has operated, including a period it was not safeguarded. Combining this estimated 6 to 33 kilograms with the plutonium content of the removed 1989 irradiated fuel from the 5 MW, “power” reactor results in a possible 13 to 47 kilograms of plutonium.

The efficiency of operation of the IRT-DPRK has a significant impact on the quantity of plutonium produced; this can be investigated by assuming various load factors. The effectiveness of the safeguards during the period that the IRT-DPRK operated also affects the quantity of plutonium that could have been produced. The IRT-DPRK was not safeguarded from 1965 to 1977 and then was placed under a Type 66 agreement. Since the IAEA safeguards criteria do not effectively cover research reactors smaller than 25 MW, it is unlikely that the safeguards were sufficient from 1977 to 1996.
NOTES AND REFERENCES


3. Ibid., p. 53.

4. Ibid., pp. 50-51.


6. Albright, op. cit., p. 52.


9. ACT editor, op. cit.


11. Albright, op. cit., p. 52.

12. Ibid., p. 47.

13. Americium-241 is a decay product of plutonium-241, it dates the time that the plutonium was separated.

14. We utilize the following expression for our estimated maximum plutonium production (EMPu) calculations: \[ \text{EMPu} \left[ \text{kg/yr} \right] = 0.224 \times \frac{\text{kg}}{\text{MW}_r \cdot \text{yr}} \times \text{Operating Power Level} \left[ \text{MW}_r \right] \]. The assumptions upon which this expression is based have been confirmed in the study of the unreported plutonium production at six research reactors.